

A PROCESS FOR RUNNING PROGRAMS ON PROCESSORS AND
CORRESPONDING PROCESSOR SYSTEM

BACKGROUND OF THE INVENTION

Field of the Invention

5 The present invention relates to processors and methods for processing signals that can be implemented using said processors.

Description of the Related Art

In cell-phone systems of the second generation (for example GSM) or of a more advanced type (GPRS, EDGE, UMTS), the most widely used

10 architecture consists of a system made up of two processors. The first processor, which is specialized in handling the part with the largest computational burden, typically consists of a Digital Signal Processor or DSP. The other processor, with tasks of control, synchronization and execution of high-level applications, is typically configured as a CPU.

15 An example of architecture of this sort is illustrated in Figure 1, where the aforesaid processors, designated respectively by DSP and CPU 1, are illustrated together with the cache memories associated thereto, namely together with instruction cache memories I\$ and data cache memories D\$, respectively.

Designated by CMC are the interface modules, referred to as Core
20 Memory Controllers, which enable two sub-systems coming under the two processors DSP and CPU 1 to interface with one another by means of a main bus B with the main system memory MEM and with the various peripheral units P1, P2, P3, P4, ... associated to the system.

The specific application in the telephony sector is, on the other hand, referred to herein purely in order to provide an example and consequently does not imply, even indirectly, any limitation of the altogether general character of the

invention described in what follows. The said invention may, in fact, be applied in all those fields in which it may be useful or advantageous to employ a microprocessor.

With reference to the diagram of Figure 1, the CPU 1 is typically a

5 32-bit pipelined scalar microprocessor. By "pipelined scalar" is meant that its internal architecture is made up of different logic stages, each of which contains an instruction in a very specific state. The said state may be that of:

fetching of the instruction from the memory,
decoding of the instruction,
10 addressing of a register file,
execution,
writing/reading of data from the memory.

The number of bits on which the CPU 1 operates is related to the width of the data on which the machine is operating. The instructions are
15 generated and executed in turn, in a specific order defined by compiling.

The other processor, designated by DSP, is typically a superscalar microprocessor or 128-bit pipelined VLIW (acronym for Very Long Instruction Word) microprocessor.

"Pipelined superscalar" means that its internal architecture is made
20 up of different logic stages, some of which are able to execute instructions in parallel, for example in the execution step. Typically, the parallelism is of four instructions each (equal to 128 bit) whilst the data are expressed in 32 bits.

The processor is said to be superscalar if the instructions are re-ordered dynamically in the execution step in order to supply the execution stages
25 which can potentially work in parallel, also altering the order generated statically by compiling of the source code, if the instructions do not present any mutual dependence. The main disadvantage of this approach lies in the complexity of the resulting machine, in which the logic of scheduling of the instructions may prove one of the most important parts in terms of number of gates.

The term VLIW processor is used if the instructions are re-ordered statically in the compiling step and executed in the pre-set order, which is not modifiable in the execution step. The advantage of the said approach is that it eliminates all the logic of management of the scheduling since this task is 5 performed during compiling.

The main disadvantage lies in the fact that the compiled code is strictly dependent upon the implementation of the machine on which it is executed. For example, given the same instruction-set architecture (ISA), a machine with N execution units cannot execute a compiled code for a machine with K execution 10 units if K is not equal to N. From this it follows that there is no "binary compatibility" between different generations of processors with the same ISA.

It is to be recalled that by "binary compatibility" is meant the property existing between a group of processors each of which is able to execute one and the same binary machine-code datum.

15 Likewise, it is not possible to create multiprocessor systems (each with a different number of execution units), which can change processes in the course of execution.

In the diagram of Figure 1, each processor possesses its own data cache D\$ and its own instruction cache I\$, so as to be able to load from the main 20 memory MEM both the data on which to operate and the instructions to be executed in parallel. Since the two processors CPU 1 and DSP are connected to the main memory MEM through the system bus B, the two processors are typically found competing for access to said memory when an instruction and/or the data on which they are to operate must be located in the main memory, the said instruction 25 or data not being available in their own caches.

A system based upon the architecture represented in Figure 1 has a sharing of work and of processes that is rigid and not modifiable, such as to render asymmetrical the workload and the software programs to be executed.

By way of reference, a processor such as the CPU 1 usually possesses 16 Kbytes of data cache and 16 Kbytes of instruction cache, whereas the DSP usually possesses 32 Kbytes of data cache and 32 Kbytes of instruction cache.

5 The flowchart of Figure 2 illustrates the logic diagram of the CPU described from top to bottom. The first stage, designated by 10, generates the memory address to which the instruction to be executed is associated, the said address being referred to as program counter. The stage 10 is hence configured typically as a fetch stage, whilst the instruction thus loaded is decoded in the stage 10

10 12 separating the bit field which defines its function (for example, addition of 2 values contained in two registers located in the register file) with respect to the bit fields which address the operands. The said addresses are sent to a register file from which (in a stage designated by 14) are read the operands of the instruction. The operands and the bits which define the function to be executed are sent to the 15 execution unit which, in a stage 16, performs the desired operation, for example the operation of addition referred to previously. The result can thus be re-stored in the register file in a stage 18 currently called write-back stage.

20 The process schematically represented in Figure 2 operates in combination with a load/store unit which enables reading/writing of any possible data in memory with the aid of specific instructions dedicated to the purpose.

It may be readily appreciated that the set of instructions is in biunique correspondence with a given microprocessing CPU architecture.

25 The flowchart of Figure 3 shows, instead, the logic diagram of the DSP. Also in this case, there is envisaged an initial fetch stage 20, associated to which there is logically cascaded a stage 20a for issuing instructions. The reference number 22 designates, instead, a decoding stage whilst the reference number 24 designates a register file (see the stages 14 and 16 of Figure 2). The reference number 28 designates a stage for re-storage in the register file, which is in general akin to the stage 18 of Figure 1. In the diagram of Figure 3 the

reference number 26 designates collectively a plurality of execution stages that can be executed in parallel.

Both in Figure 1 and in Figure 3 the reference CW designates the branching lines of the control words.

5 It will be appreciated that the main difference between the diagram of Figure 2 and the diagram of Figure 3 is provided by the fact that the diagram of Figure 3 envisages the possibility of working in parallel on different sets of instructions. Another difference lies in the fact that the diagram of Figure 3 envisages the use of a greater number of execution units available, which can
10 operate in parallel in a superscalar and VLIW processor. In both cases, the set of instructions is in biunique correspondence with a given microprocessing architecture.

Assuming that the two sets of instructions designed to be executed by the processors CPU 1 and DSP are different from one another (as is commonly
15 the case with the architecture of wireless processors) it is understandable that instructions (and hence tasks to be executed), which can be executed the processor CPU 1 cannot be executed by the DSP, and vice versa.

For the above to be possible, it is necessary to compile each process for each processor, thus increasing the memory of the program. Whenever a
20 process is to be executed by a specific processor, it is then necessary to load and execute the code of the particular task that has been compiled for that processor. There is moreover encountered the problem linked to the fact of having to correlate the different points of partial execution of the programs when they are to be shifted from one processor to another (*i.e.*, re-map the program counters correctly) and of
25 having to convert all the processing data from the representation system of one processor to the representation system of another (for example, the contents of the state and general-purpose registers).

The above problems are difficult to solve, so that in general a process is compiled and executed on a single processor.

With reference to Figures 4 and 5, it is possible to consider a sequence of sets of instructions of said processes.

In general, two types of processes are distinguished, namely:
those corresponding to the operating system and to applications that

- 5 use calls to functions of the operating system, and
those regarding the processing of multimedia (audio/video/graphic) contents.

Specifically, in the diagram of Figure 4 the references OsTask 1.1, 1.2, etc. illustrate processes which can be executed by the processor CPU 1. The 10 processes designated by MmTask2.1, MmTask2.2, MmTask2.3, identify, instead, processes compiled so as to be executed by the DSP.

Starting from the diagram of Figure 4, which illustrates a possible assignment of the task to two processors, it is immediately possible to return to the diagram of Figure 5, which illustrates the corresponding flow of instructions.

- 15 Setting equal to one hundred the total time of execution of the processes, it is noted that the first processes typically last 10% of the time, whilst the second occupy a much greater part, corresponding to 90%.

Again, the first processes contain instructions generated by the compiler of the processor CPU 1 and hence can be executed by the latter, but not 20 by the DSP. For the latter processes the situation is exactly complementary, in the sense that they contain instructions generated by the compiler of the DSP and can hence be executed by the said processor, but not by the other processor CPU 1.

It is moreover to be noted that the processor CPU 1 is characterized by a compiling flow of its own, which is independent of and distinct from that of the 25 DSP.

Given the modest workload, it may be appreciated that the processor CPU 1 could even be turned off when not in use, so enabling a considerable energy saving.

The above hypothetical solution (switching-off of the processor CPU 1 when it is not being used) comes up, however, against the fact that the corresponding switching-off or powering-down procedures introduce additional processing latencies and these are added to the value of 10% mentioned previously.

5 The aforesaid procedures envisage in fact:

switching off the processor CPU 1, except for the respective register file by gating the clock signal which supplies all the internal registers;

switching off the processor CPU completely, except that power supply is maintained for the cache memories; and

10 switching off the CPU as a whole, including the data and instructions caches.

However, given that the state of the individual processor must be restored when the latter is turning back on following upon one of the operations referred to previously, the latencies introduced vary from tens of microseconds to 15 tens or hundreds of milliseconds. The above latencies prove particularly costly, both from the energy standpoint and from the computational standpoint.

Finally, the DSP is forced to work at approximately 90% of its computational capacity. This implies an evident asymmetry in the workload of the processor CPU as compared to the workload of the DSP, an asymmetry which is 20 revealed also in the power-management algorithms, which are distinct for the two processors.

BRIEF SUMMARY OF THE INVENTION

The purpose of the present invention is to provide a solution capable of overcoming the drawbacks outlined previously.

25 According to the present invention, the said purpose is achieved thanks to a procedure having the characteristics referred to specifically in the claims that follow. The invention also regards the corresponding processor system, in particular multiprocessor system.

The present invention thus offers a solution, which enables:
execution of programs indistinctly on two or more processors, for
example of the VLIW type, constituting a system in dynamically variable working
conditions; and

5 assurance of binary compatibility between two or more processors, in
particular VLIW processors having a different maximum long-instruction-word
length.

The above is achieved, at the same time ensuring that in order to
support the execution of the processes, the use of an asymmetrical multi-
10 processing architecture is not necessary.

Basically, the solution according to the invention makes it possible to
provide a multiprocessing architecture comprising a plurality of processors.

In the application described in detail purely by way of example in
what follows, the processors considered are all of the VLIW type. The solution
15 according to the invention is, however, applicable, for example, to architectures
comprising one or more VLIW processors in combination with at least one
superscalar processor, the only important aspect being that the processors in
question should have the same instruction-set architecture (ISA).

The solution according to the invention is in fact based upon the
20 recognition of certain essential facts.

Consider, in the first place, two or more processors (for reasons of
simplicity, in what follows reference will be made only to VLIW processors) having
the same instruction-set architecture (ISA), this implying that on each of them a
linear sequence of basic instructions can be executed. Each process/task has
25 been compiled for a certain VLIW processor as a flow of long instructions in which
the longest has a dimension corresponding to the parallelism at the instruction
level for which the VLIW processor has been designed.

Each VLIW processor can execute instructions with a different
maximum length; for example, the first can execute at the most four basic

instructions in parallel for each clock cycle, whilst the second can use at the most eight instructions in parallel for each clock cycle.

Each processor has a unit for issuing instructions, which typically reads from the instruction cache a number of instructions equal to the number that

5 it is able to handle in parallel. For example, if the processor is able to handle in parallel up to four instructions, the corresponding unit for issuing instructions may read simultaneously up to four instructions but not more.

It is possible to envisage for a second VLIW processor a modified-instruction unit which is able to read at input words corresponding to very long

10 instructions originally compiled with a view to their execution on a first VLIW processor and to issue at output words corresponding to very long instructions ready to be executed on the second VLIW processor.

The above change in the length of the instructions may be carried out in run-time conditions, without any need for recompiling and duplicating the code:

15 each instruction in the very long instruction word has in fact been scheduled by the compiler in such a way as to be independent from the others. This result is obtained in the form of a cascade of simple splitting operations and of entry of fictitious (no-operation) instructions according to the length of the instructions of any single VLIW processor.

20 In order to enable dynamic re-allocation of a process compiled and executed on a first VLIW processor so as to execute it on a second VLIW processor, there is kept, in the system memory, a table which stores the information corresponding to each process in terms (it may amount to a simple order number) which identify the VLIW processor for which it has been compiled,

25 together with an identifier (also in this case it may simply be a number) which identifies the last VLIW processor on which, within the plurality of processors comprising the multi-processor architecture, the process has been executed, as well as the co-ordinates for tracing the context of the process in the main memory.

“Context of a processor” is here meant to indicate basically:

the value of the program counter;
the contents of the register file; and
the data stack memory.

Using the solution according to the invention it is possible to achieve

- 5 a considerable simplification in terms of programming environment and requirements of memory and power absorption. Furthermore, the solution according to the invention solves a major problem in the framework of VLIW processors, namely, that of binary compatibility between architectures and different parallelisms, enabling for example the dynamic transfer of the process workload
- 10 between VLIW processors that are symmetrical from the point of view of the instruction set and asymmetrical in terms of parallelism of instruction.

BRIEF DESCRIPTION OF THE DRAWINGS

The invention will be now be described, purely by way of non-limiting example, with reference to the attached drawings, in which:

- 15 Figures 1 to 5, which regard the prior art, have already been described previously;
- Figure 6 illustrates, in the form of a block diagram, the architecture of a multiprocessor system that is able to operate according to the invention;
- Figures 7 and 8 illustrate in greater detail the criteria for handling processes in the framework of an architecture operating according to the invention;
- 20 Figure 9 illustrates the criteria of organization of a unit for issuing instructions implemented according to the invention;
- Figures 10 to 12 illustrate details of implementation of various interventions on sets of instructions in the framework of a system operating
- 25 according to the invention, also in relation to the position in which the formatting of the instructions is carried out; and
- Figure 13 illustrates the structure of a table that is can be implemented in the framework of the invention.

Figure 14 illustrates an alternative embodiment of one system according to the present invention.

DETAILED DESCRIPTION OF THE INVENTION

From the block diagram of Figure 6, it may be realized that the said diagram essentially reproduces the general set-up of the diagram of Figure 1, already considered previously.

Unlike the architecture represented in Figure 1 (which is an intrinsically asymmetrical one, on account of the presence of the two processors CPU 1 and DSP, with different characteristics), the diagram of Figure 6 is intrinsically symmetrical, in so far as it envisages the presence of two (or more) processors of a VLIW type, here designated, respectively, as VLIW 1 and VLIW 2, which, albeit instantiated according to different criteria, operate in conditions of substantial symmetry, in so far they are able to execute the same processes, without this requiring recompiling or duplication of the object codes for the two processors, it being at the same time altogether possible to allow for the presence of two (or more) VLIW processors having different hardware parallelisms.

In particular, with reference to Figures 7 and 8, consider, in a first step, compiling the source code of a process referred to as Task1 corresponding to the operating system, to be executed on the processor VLIW 1 (see the diagram of Figure 6) and with the corresponding compiler. It will be likewise assumed that at most the said processor can execute in parallel four instructions for each clock cycle.

Moreover, consider, in the self-same step, compiling the source code of a process referred to as Task2, regarding for example the audio/video/graphic multimedia application, to be executed (refer again to the diagram of Figure 6) on the processor VLIW 2, and with the corresponding compiler. It will likewise be assumed that at the most the processor VLIW 2 can execute eight instructions in parallel for each clock cycle.

Of course, the aforesaid values (four and eight, respectively) and the fact of referring to - two - VLIW processors correspond purely to requirements set by way of example, without any intention of limiting the scope of the invention.

It is moreover to be recalled that the two processors VLIW have the 5 same instruction-set architecture (ISA). This means that they are defined by the same list of instructions, syntax and semantics, and length (for example 32 bits per basic instruction).

Figure 8 shows how the aim is to associate statically and dynamically each of the processes indifferently on each of the two processors VLIW 1 and 10 VLIW 2 on the basis of decisions that can change dynamically. These may, for example, be decisions based upon the dynamic load of each of the processors, upon the dynamic operating frequency, and upon instantaneous energy consumption, the final purpose being to split the workload evenly on the two processors.

15 Again, it is to be noted that each of the two (or more) processors considered is able to function with a different working frequency, so that each processor may dynamically change the operating frequency without jeopardizing its proper operation.

For example, the Task1, as shown in Figure 7, is compiled for 20 generating a flow of long instructions with a maximum length of four, assuming that they are to be executed on the processor VLIW 1.

The Task2 is, instead, compiled for generating a flow of long instructions with a maximum length of eight, assuming that the intention is to execute them on the processor VLIW 2.

25 Again by way of example, it is assumed that the intention is to reverse the association defined above, with the aim of associating the Task2 to the processor VLIW 1 and the Task1 to the processor VLIW 2.

Figure 9 shows how the so-called instruction-issue unit (IIU) of a processor, as noted in Figure 3, has to be modified for carrying out the following

task with the purpose of ensuring binary compatibility without duplicating the object code.

Assume that the IIU proposed by the processor VLIW 1 receives instructions that are 8×32 bits long whereas the processor is able to execute at the 5 most 4×32 bits per cycle.

The IIU will thus have to split the instructions at input into two instructions that are 4×32 bits long.

Now assume that the IIU of the processor VLIW 2 receives instructions that are 4×32 bits long, whereas the processor is able to execute at 10 the most 8×32 bits per cycle.

The IIU in question must thus lengthen the input instruction by means of 4×32 bit null instructions of the no-operation (nop) type.

A typical example (well known to persons skilled in the sector) of a 15 nop instruction is the instruction for carrying out the addition of the number 0 with itself to be written in the register that contains the said 0, which is one just for reading. It is therefore an instruction that expresses a deliberate nonsense. Furthermore, the nop instructions cause switching-off of four of the eight functional units, so reducing the power consumption of the processor VLIW 2.

The examples considered above can evidently be generalized in the 20 following way:

1. Consider L_1 to be the maximum length of the long instruction of which the processor VLIW 1 enables execution: for example, VLIW 1 can execute up to 3 instructions in parallel, each 32 bits long.
2. Consider L_2 to be the maximum length of the long instruction 25 of which the processor VLIW 2 enables execution: for example, VLIW 2 can execute up to 3 instructions in parallel, each 32 bits long.
3. Let $L_1 \geq L_2$.
4. Let $A = L_1/L_2$ be the integer result of the division between L_1 and L_2 . For simplicity, assume that the said result is equal to four.

5. Let B be the integer remainder of the operation L1/L2, a remainder which is evidently smaller than of L2. It may be assumed, for example that the said remainder is equal to 1.

6. The intention is to execute an instruction of length L1 on the 5 processor VLIW 2.

Consequently:

if B is equal to zero, the length L1 is broken down into A long instructions L2;

10 if B is other than zero, L1 is broken down into A long instructions L2, to which there is to be added a further long instruction L2, made up of the remaining instructions of L1 not used for composing the previous A long instructions L2, corresponding to B instructions of the set L1, by further adding L2 - B nop instructions.

7. The aim is to execute an instruction of length L2 on the 15 processor VLIW 1; hence to the instruction L2 there must be added L1 - L2 nop instructions.

It will be appreciated that the same criteria apply if $L2 > L1$, it being sufficient to change the index 1 with the index 2 without jeopardizing the generality of the method.

20 Figure 9 illustrates a further example of what has been said above, an example which relates specifically to the case where L1 is equal to 4 and L2 is equal to 8.

Another solution, which refers specifically to Figures 10 and 11, may consist in rendering explicit, in the machine instructions of the processor, different 25 bits referred to as "stop-bundle" bits corresponding to different word lengths, *i.e.*, different maximum levels of parallelism executable by the machine.

In the case of Figure 10, a processor built with parallelism A uses as stop-bundle indicator the bit 31, ignoring the bit 30. Instead, a processor built with parallelism B uses as stop-bundle indicator the bit 30, ignoring the bit 31. The

verification of the end of bundle is made normally at the level of instruction-issue unit (IIU), since each processor has an associated instruction cache I\$ and (potentially) a compressor/decompressor of the code to be executed. The solution illustrated in Figure 10 may be generalized as described in what follows.

5 Given a generic instruction set with instructions encoded on N bits (for example, let N = 32), assume moreover that one of said bits encodes the stop-bundle instruction for the processor. To these words are added K bits, which encode the stop-bundle information for different lengths of word. For example, if K = 4, the 4 bits in question encode the stop-bundle information for lengths of 2, 4,
10 6, and 8, respectively.

In the decoding step, *i.e.*, in the cache re-fill step, or else in the code-decompression step, the operation of placing the appropriate stop bundle in the "effective" instruction bit can be carried out according to the parallelism of the machine which is executing the code. In this connection see Figure 11.

15 In particular, in said figure there may be noted, in the top part designated by A, a situation in which the bit 31 has not envisaged entry of a stop-bundle information datum, this as regards the bit 31 of the portion of the instruction, designated by AI, in which the instruction proper is entered. In the instruction appendix, designated by IA, there are instead entered the stop-bundle
20 information data, and in particular for output widths of 2 (SB2), 4 (SB4), 6 (SB6) and 8 (SB8), respectively.

The situation represented in Part B of Figure 11 refers instead to execution on a machine with width 4. In the said situation, the stop bundle for the width of 4 is placed in the instruction corresponding to the bit 31. The above
25 comprises the consequent possibility of rejecting the part of appendix IA, so as to give rise to an instruction format represented in Part C again of Figure 11. The module which performs the operation just described is defined as "instruction-formatting" module or "instruction formatter".

The operation just described may be carried out in different positions in the system. It will again be noted that in Figure 10 there are represented, proceeding from the top down, the different possible combinations of the bits in positions 30 and 31, designed to function as stop-bundle bits for the output widths

5 B (bit 30) and A (bit 31), *i.e.*, the following four cases:

absence of end of bundle,
end of bundle A,
end of bundle B, and
end of both bundle A and B.

10 It may be noted from Figure 12, that it is possible to place the aforesaid formatter, designated by IF, between the possible decompressor of instructions CD and, in any case, between the main memory MM and the instruction cache I\$. Alternatively, the formatter IF may be positioned immediately before the VLIW processor and hence after the cache I\$ or even in the decoding
15 stage of the VLIW processor. This latter case is the same as the one described previously with reference to Figure 10 for K = 2, N = 30.

20 In the compiling step, then, the compiler generates all the additional (stop-bundle) information for all the output widths envisaged in the instruction appendix IA. The above will then be used by the formatter IF according to the configuration thereof.

The operation performed by the formatter IF consists only in entering a bit and eliminating the appendix IA. These are operations which can be implemented in an elementary way at the hardware level, as will be evident to persons skilled in the sector.

25 The instructions that make up the task of Figure 8 are present in the system memory MEM and are addressed by means of the program counter provided in each VLIW processor envisaged (see Figure 6).

The above instructions are loaded by the fetch unit of Figure 3 and appropriately adapted to the parallelism of the processor according to the solution

implemented by the unit IIU described previously with particular reference to Figure 9.

The solution according to the invention offers the important advantage provided by the complete binary compatibility between the two (or 5 more) processors, this compatibility being understood as capacity for executing indistinctly said process on the various VLIW processors comprised in a multiprocessor system using the same compiled code without any needless duplications. The said capacity moreover enables dynamic distribution of the computational load on the various processors so as to be able to equalize the 10 operating frequency of the processors themselves with respect to the maximum point. There is thus achieved a saving in dissipated power which, as is known, is linearly dependent upon the operating frequency of the processor.

In order to provide a fuller clarification of how it is possible to shift the execution of a process from one VLIW processor to another, consider the 15 existence of a table stored in the memory MEM of the system.

With reference to Figure 13, from left to right, the table shows:
a list of processes (Process) that are being executed or are suspended on any single processor;
the progressive number (Num) thereof on the basis of the order of 20 activation;
the percentage (% VLIW) of maximum power of the processor that is used for said process;
the execution time (Exec.time) which, if zero, designates that the process is temporarily suspended from being executed;
the amount of memory (Memory) of the system used by the process 25 to be able to execute the function for which it is responsible;
the maximum length (Compiled For VLIW Of Length) of the long instruction which the VLIW processor can execute and for which it had been generated during compiling;

maximum length (Execution On VLIW Of Length) of the long instruction of the VLIW processor on which it is executed; and the address of the portion of memory (Memory address) in which the data and the instructions are stored, in other words the context.

5 The above table is accessible by a process referred to as control process, which is executed for a pre-set time on each of the VLIW processors. By means of the said process, each processor has thus the possibility of consulting and updating the table in order to equalize its own workload with respect to the second processor. The said table likewise contains the co-ordinates whereby a 10 processor can take possession of and execute one of the processes listed.

The solution described may evidently be extended to any number of VLIW processors which make up the system and each of which may have any maximum length whatsoever of the long instruction to be executed, where said length may vary from one processor to another.

15 Figure 14 is a further alternative embodiment of one system according to the present invention. The system of figure 14 includes an instruction bus 25, which contains a plurality of instructions to be carried out by the system. The system also includes a first processor 27, a second processor 29, and a third processor 31. Appropriate connection is made via the instruction bus 25 to the 20 first, second and third processors in order to provide instruction sets to them. Such connections can be made by software, hardware or other appropriate connection lines.

A memory 37 is also connected via the appropriate connection line 33 to the bus 25 for storing instructions, storing data and being available to each of 25 the processors 27, 29, 31 through appropriate connection lines 34 for exchanging data and instructions with each of the processors.

It will be appreciated that each of the processors have their own on-board memory, such as cache memory, instruction set memory, or registers as

appropriate. They use either the local memory within the processor or the main memory 37 shared by each of the processors.

The first processor 27 receives an indication of the amount of work being performed by the second processor via a workload sense line 39 from the second processor 29 to the first processor 27. The first processor 27 also receives an indication of the amount of work being performed by the third processor via a workload sense line 41 from the third processor 31 to the first processor 27.

The workload sense lines 39 and 41 can sense various characteristics of the workload of each of the processors. For example, they may sense the power consumption of the processors, the number of operations carried out, the amount of memory exchanges or memory usage of the processors, the number of interruptions, and other characteristics, which are indicative of the work actually being performed by the respective processors.

The first processor 27 is, therefore, able to receive data from each of the processors in order to determine the level of work performed by each of them.

In one embodiment, the workload capacity of each of the processors in the plurality is stored for access by the first processor. For example, the second processor 29 may be a medium-sized processor having a medium rated power consumption and a certain rated speed of operation. The third processor 31, or additional *n*th processors 31 within the set, may have different power capacities and different operating speeds. For example, the third processor 31 may have a much larger power usage capability and a much higher capacity for processing information, executing instruction sets, interacting with memory and other characteristics. According to the alternative embodiment, the first processor 27 will compare the workload of each of the processors with the work capacity of each of the processors. Then, the first processor 27 will direct the instruction sets to the processors based on the available capacity of the respective processors. Thus, in one embodiment, for example, the power consumption of the both of the processors may be the same, but one of the processors may have a much higher

power rating so that one of the processors is working at near its maximum rated power while the other processor is working at much lower than of its rated power. In such an instance, the work flow would be shifted from the processor operating at its maximum power to the other processor so as to increase its power consumption

5 and the number of instruction sets being carried out so it is operating closer to its rated capacity.

In this alternative embodiment, the rated capacity is stored in a first memory which the first processor 27 can access, either onboard or within the memory 37, and then the processor's operational characteristics are compared to

10 its rated capacity and the workload is increased or decreased for that particular processor depending on whether it is operating at its peak rated capacity or substantially less than its peak, respectively. If it is operating at its maximum capacity in all respects, it would be anticipated that the processor is unable to process more instruction and therefore the instruction set flow to that processor will

15 be reduced and shifted to other processors in the set. Conversely, if it is operating at substantially less than its rated capacity, then the work flow to the processor may be increased. In the alternative embodiment, the work flow to a particular processor is modified based on that particular processor's capacity to perform additional work rather than an absolute value of the work being performed as

20 compared to the other processors.

Of course, without prejudice to the principle of the invention, the details of implementation and the embodiments may be amply varied with respect to what is described and illustrated herein, without thereby departing from the scope of the present invention, as defined in the annexed claims.

25 All of the above U.S. patents, U.S. patent application publications, U.S. patent applications, foreign patents, foreign patent applications and non-patent publications referred to in this specification and/or listed in the Application Data Sheet, are incorporated herein by reference in their entirety.

From the foregoing it will be appreciated that, although specific embodiments of the invention have been described herein for purposes of illustration, various modifications may be made without deviating from the spirit and scope of the invention. Accordingly, the invention is not limited except as by

5 the appended claims.